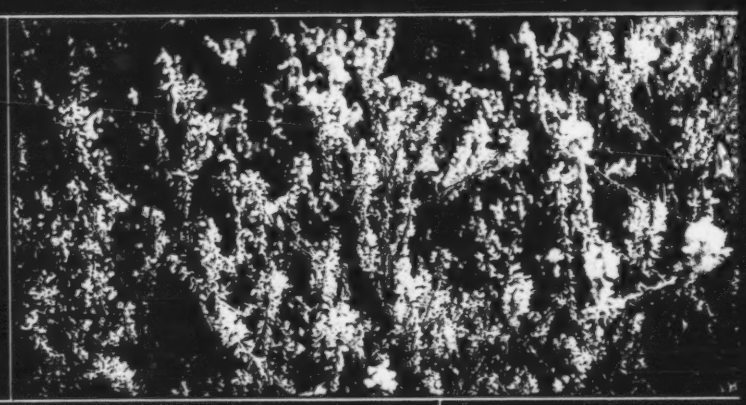
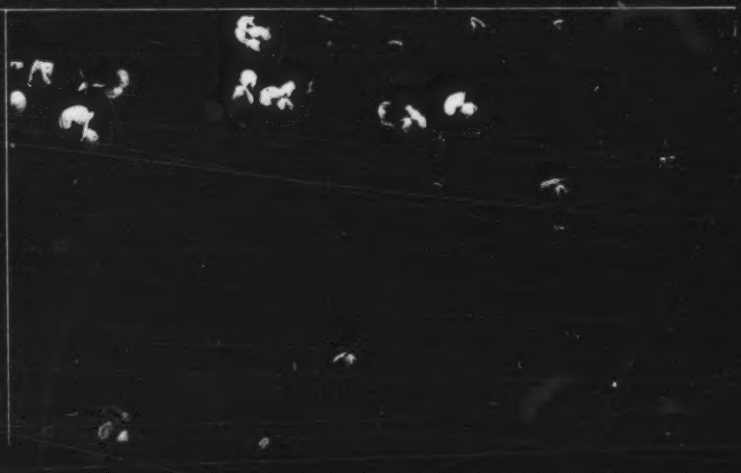
Saskatchewan
Agriculture
Soils and Crops
Branch

Soil Improvement With Legumes

including Legumes in Crop Rotations





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Contents

	Page
Introduction	
What are Legumes	1
Past Trends in Soil Fertility and Use of Legumes	1
Nitrogen Fixation	
The Nitrogen Fixation Process	3
Efficiency of Nitrogen Fixation Versus Fertilization	4
Role of Legumes	
Effect of Legumes on Soil Quality	5
Effect of Legumes on Subsequent Production	7
Management of Legumes for Soil Improvement	7
Limitations to Use of Legumes	8
Legume Choice and Management	
Annual Legumes	9
Biennial Legumes	9
Perennial Legumes	12
Legume Inoculation	
Need for Inoculation	14
Inoculant Types and Quality	15
Methods of Inoculation	16
Chemical Seed Treatments	17
How to Check for Nitrogen Fixation	18
Equipment Requirements	
Seeding	19
Incorporating Green Manure	21
Harvesting Legumes	22
Conclusions	22
Appendix of References	23
Soil Zones of the Prairie Provinces	24

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Soil improvement with legumes

Summary

- Legumes increase soil nitrogen and organic matter.
- Legumes improve soil structure.
- Legumes in rotation reduce soil erosion and degradation.
- Legumes in rotation improve soil water holding capacity.
- Deep rooted legumes help to re-cycle nutrients leached below the root zone of other crops and move salts down in the profile arresting the spread of salinity.
- Growing legumes in rotation requires special management for weed, disease and insect control.
- The large water use by biennial and perennial legumes may result in lower subsequent crop yields where moisture supply is limited.

Introduction

What are Legumes?

Legumes are plants that bear their seeds in pods, such as peas and beans. They are used for seed, hay, dehy, silage, green manure and pasture. Legumes are rich in protein since much of their nitrogen is produced through fixation of atmospheric nitrogen by bacteria in nodules on their roots. In this respect they differ markedly from grasses, cereals and other non-legume crops.

Table 1 Legumes Grown in Saskatchewan

Perennial Legumes:	**alfalfa, red clover, alsike clover, sainfoin, birdsfoot trefoil**
Biennial Legumes:	**yellow sweetclover, white sweetclover**
Grain Legumes:	**fababeans, field peas, lentils, beans, chickpeas**

World-wide there are more than 16,000 known species of legumes, including herbs, shrubs and trees, but only about 200 are cultivated. In Saskatchewan, only 12 legume species are grown commercially (Table 1), although many more species are grown experimentally for selection and evaluation by researchers. Species are further divided into varieties. For instance, more than 10 named alfalfa varieties are grown in Saskatchewan.

The ability to convert nitrogen from the air to a form available to plants is characteristic of all cultivated legumes. It provides farmers with an effective means for maintaining their cultivated land in a fertile and productive state.

Past Trends in Soil Fertility and Use of Legumes

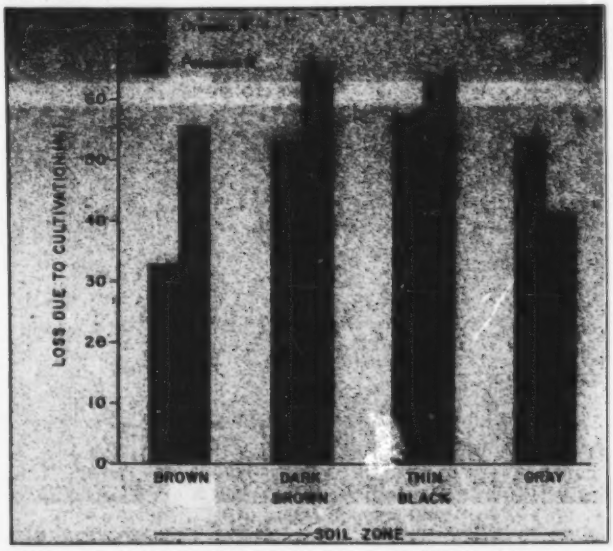
Forage legumes, such as alfalfa and sweetclover, were grown in rotation with cereals soon after the homesteaders first broke the prairie grassland around the turn of the century. In these early years legumes generally failed to improve the soil conditions because the recently broken soils still had good structure and large reserves of organic matter. Furthermore, their levels of available nitrogen were so high that biological nitrogen fixation was largely inhibited. As soil organic reserves decreased with continued tillage and cereal cropping, legumes gradually gained importance on the prairies until the practice of green manuring, i.e., turning green plant material into the soil to increase organic matter, peaked in the 1940's.

After World War II, farming was rapidly mechanized and traditional "legume-cereal" rotations were abandoned as relatively cheap nitrogen fertilizers became widely available and appeared to be more efficient than legumes in increasing grain yields. Another reason for the declining use of legumes in rotations was the mounting evidence that deeprooted legumes frequently depressed the yields of following grain crops by depleting soil moisture reserves, particularly in the drier regions of Western Canada (Brown and Dark Brown soil zones).

However, in recent years, the wheat-fallow rotation has come under increasing criticism. Fallowing is considered to be a major cause of the serious decline in productivity of prairie soils. Frequent summerfallowing has hastened this decline by effecting large decreases in soil organic matter, marked increases in soil erodibility, a serious wastage of soil nitrogen and water, and an alarming increase in soil salinity.

During the first 70-80 years of cultivation, wheat-fallow cropping practices on the prairies have generally resulted in a loss of 40 to 50% of the organic matter in the top 15 cm (6 in) of soil and there has also been some loss from the 15-30 cm (6 - 12 in.) depth. Cultivation, especially during summerfallowing, has not only reduced the humus content, but to a greater extent the soil's potential to supply nitrogen to plants (Figure 1, Figure 2).

Figure 1 *Effect of Cultivation on Loss of Potentially Mineralizable Nitrogen and Organic Nitrogen in Some Saskatchewan Soils 0-15 cm. (0-6 in.)*

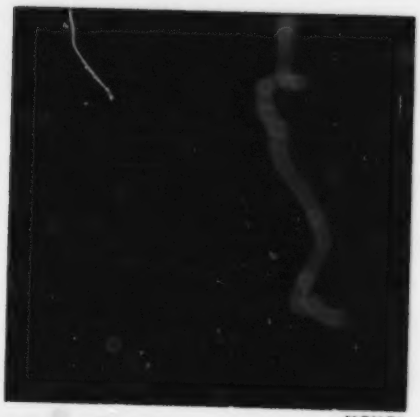


Source: C.A. Campbell and W. Souster. Can. J. Soil Science, Volume 62:651-656 (1982)

Figure 2 shows the net N mineralized from the soil during an average summerfallow period in Saskatchewan. The N comes from two sources, the soil humus and the recently grown straw, rootlets and soil microbes. The horizontal line represents the amount of N required by a 1700 kg/ha (25 bu/ac) wheat crop.

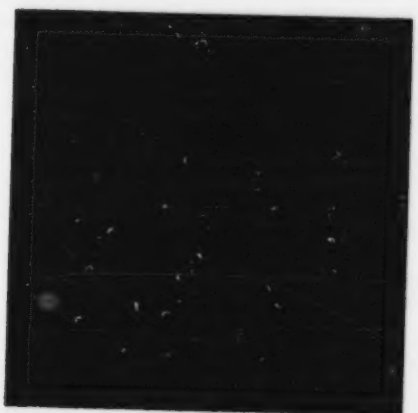
The graph shows that when prairie sod was broken and tilled for growing grain the amount of N released from the rich prairie soils during a fallow period was more than enough to grow a crop. The straw could have been used and if removed, there would still have

SOME LEGUMES GROWN IN THE PRAIRIE PROVINCES



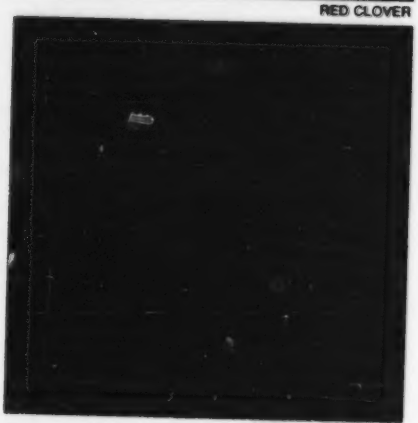
ALFALFA

RED CLOVER



ALSIKE CLOVER

SAINFOIN



BIRDSFOOT TREFOIL

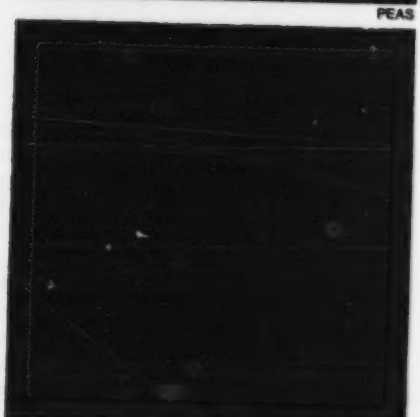
YELLOW AND WHITE BLOSSOM SWEETCLOVER

FABABEANS

PEAS

LENTILS

BEANS



CHICKPEAS

Figure 2 *A Model Showing Past, Present and Future Soil Nitrogen Trends (Campbell, McGill & Paul 1981)*

been excess N produced from the humus alone to satisfy an average crop. As time has progressed, tillage and erosion have caused a large decrease in the ability of humus to supply N, and after summerfallowing for a year many soils must still be fertilized with N. Now, and even more so in the future, it will be necessary to conserve as much straw as possible and add organic matter to reduce the need for N fertilizer, to maintain a productive soil and to resist erosion.

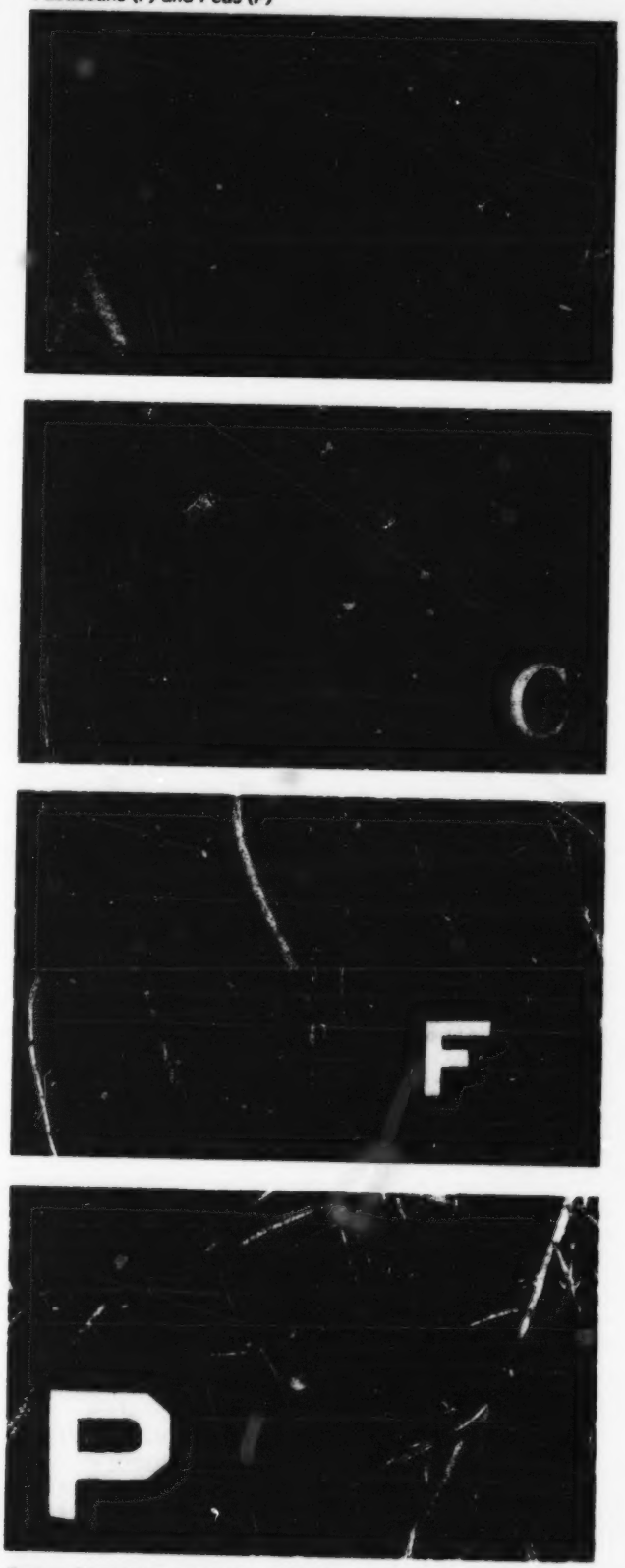
Growing concerns about declining soil fertility and rising energy and nitrogen fertilizer costs have led to renewed interest in legumes and have made biological nitrogen fixation much more attractive. Therefore, the role of legumes as a nitrogen-supplier in the rotation will gain importance in the future.

Nitrogen Fixation

The Nitrogen Fixation Process

Research has shown that the nitrogen fixation process is the most efficient way to supply the large amounts of nitrogen needed by legumes to produce high-yielding crops with a high protein content. To enable this process, legume plants must enter into a "symbiotic" or mutually beneficial partnership with certain bacteria called rhizobia. Soon after legume seeds germinate, rhizobia present in the soil or added as seed inoculum invade the root hairs and move through an infection thread toward the root. There the bacteria multiply, causing the swelling of root cells to form nodules (Figure 3) that become miniature nitrogen factories. Atmospheric nitrogen from soil air spaces around the nodules is 'fixed' by binding it to other elements and thus changing it to a plant-available form. The process requires large amounts of energy. This energy is derived from the sun as the plant manufactures carbohydrates in the green leaves and translocates a portion to the nodules. Here the carbohydrates serve as a source of

Figure 3 *Active Nodules on Roots of Alfalfa (A), Red clover (C), Fababeans (F) and Peas (P)*



Source: Microbiology Laboratory, Agriculture Canada Research Station, Swift Current

hydrogen to form ammonia (NH_3) from atmospheric nitrogen and they supply the rhizobia with the energy required to grow and to make the process go. In legume crops, the fixation of nitrogen is accomplished by plants in partnership with bacteria and by sunlight, all being renewable resources. Gaseous nitrogen (N_2) is always abundantly available for nitrogen fixation as it makes up 80% by volume of the earth's atmosphere. It is a resource that is continually renewed through the natural cycling of this element, thus maintaining a constant gas supply.

However, legumes do not depend totally on N_2-fixation by rhizobia. All legumes can and will use soil and fertilizer nitrogen. When soil contains more than 40 kg/ha. (36 lb/ac) of nitrate-N, then nodule formation will be progressively inhibited and little or no fixation may occur.

The amount of nitrogen fixed also differs for different legume species and varieties. Most grain legumes can obtain between 50 and 80% of their total nitrogen requirements from fixation, but some, like fababeans, fix up to 90% (Table 2). Well established and properly managed forage legumes will satisfy all their nitrogen requirements by fixation. The potential for nitrogen fixation is directly related to rhizobia survival, the extent of effective nodulation and plant growth factors; thus any adverse soil condition or environmental stress that affects plant growth is likely to slow down the nitrogen fixation process.

Efficiency of Nitrogen Fixation versus Fertilization

Symbiotic nitrogen fixation is very efficient in satisfying the high nitrogen requirements of legumes because the conversion of gaseous N_2 to NH_3 takes place inside the plant. Thus all of the fixed nitrogen is readily available and in the form required for combination with carbohydrates to produce the amino acids used for the manufacture of protein. Since N_2-fixation in root nodules is directly dependent on the translocation of carbohydrates from the leaves, the rate of fixation is fully "synchronized" with the rate of plant growth. This fine tuning between nitrogen supply and demand is another reason for the high efficiency of symbiotic nitrogen fixation.

By contrast, fertilization is a rather inefficient way of providing nitrogen to legumes. When fertilizer is applied to the soil some of the fertilizer nitrogen ends up beyond the reach of the roots, some is consumed by the many soil microbes present near roots, and

Table 2 N_2-Fixation in Inoculated Legumes Grown Under Irrigation in Southern Alberta

Legume	Plant-N derived from atmosphere*, %	N fixed symbiotically, kg/ha	(lb/ac)	N-fertilizer equivalent, ($/ha)**	$/ac
Alfalfa	80	300	(267)	210	85
Sweetclover	90	250	(223)	175	71
Fababeans	90	300	(267)	210	85
Fieldpeas	80	200	(178)	140	57
Lentils	80	150	(134)	105	43
Soybeans	50	150	(134)	105	43
Chickpeas	70	120	(108)	84	34
Fieldbeans	50	70	(62)	49	20

* Determined by 15N isotope techniques.
** 1984 Fertilizer Prices
Source: R.J. Rennie, Agriculture Canada Research Station, Lethbridge.

Table 3 Legume Inoculant costs relative to seed and N-fertilizer costs in 1984

Legume	Average seeding rate* kg/ha	(lb/ac.)	Inoculant cost $/ha	$/ac.	As proportion of seed cost %	As fertilizer equivalent kg N/ha	(lb N/ac)
Lentils	65	58	3.58	1.50	6.5	5.7	5.1
Fieldpeas	130	116	1.95	.79	3.5	3.1	2.8
Fababeans	170	151	9.86	3.99	12.9	15.7	14.0
Sweetclover	8	7	0.75	0.30	7.3	1.2	1.1
Alfalfa	6	5	0.56	0.23	2.2	0.9	0.8
Red clover	7	6	0.70	0.28	4.9	1.1	1.0
Sainfoin	30	27	5.28	2.13	7.8	8.4	7.5

* Based on current Saskatchewan Agriculture and Alberta Agriculture recommendations.
Source: V.O. Biederbeck, Agriculture Canada Research Station, Swift Current.

some is lost or tied up by various physical and chemical soil processes. To make use of the remaining and available portion the legume plant must expend considerable energy to transfer the nitrogen salt from the soil through the cell membranes into the roots and to reduce it from the common nitrate (NO_3) to the required NH_3 form.

Depending upon soil and climatic conditions, the fertilizer efficiency for legumes and grasses generally ranges between 20 to 50%. This means that, at best, only half of the applied fertilizer nitrogen will actually end up in non-nitrogen-fixing plants at maturity.

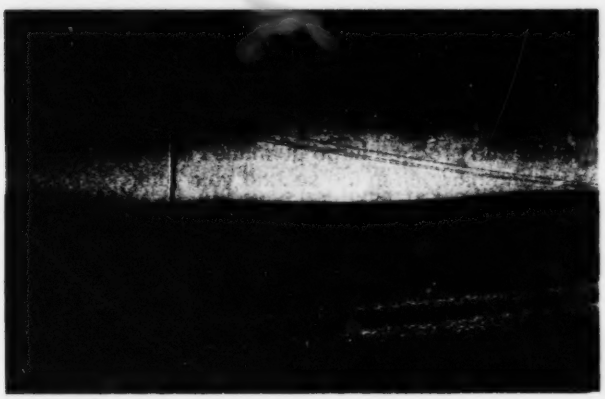
Role of Legumes

Effect of Legumes on Soil Quality

Legumes have long been recognized and valued as "soil building" crops. Until commercial fertilizers became readily available the inclusion of legumes in the rotation was the most effective means of sustaining soil fertility for grain producers. The growing of legumes improves soil quality through their beneficial effects on soil biological, chemical and physical conditions. When properly managed, legumes will:

- enhance the N-supplying power of soils
- increase the soil reserves of organic matter
- stimulate soil biological activity
- improve soil structure
- reduce soil erosion by wind and water
- increase soil aeration
- improve soil water-holding capacity
- make the soil easier to till

The extent of these soil improvements depends mainly on the type of legume used, the quantity of plant material returned to the soil, and the soil and climate conditions. Thus the greatest benefits are generally obtained with deep-rooted perennial legumes, grown as green manures, on soils with poor structure and low organic matter where annual rainfall is sufficient for good growth. The use of legumes for soil improvement is essential on many soils such as the Gray and Degraded Black soils, salt-affected soils, sandy soils and highly erosive soils. In fact, the use of legumes has enabled the agricultural development of large areas of marginal land in northwestern Canada where the initial soil quality was too low for economic grain production.



Eroded Knolls

Grain legumes generally have smaller and shorter-lived effects on soil quality than perennial legumes. The amounts of N_2 fixed by grain legumes and their influence on soil physical conditions are limited by their typically small and shallow root system and very short growth period. As the major portion of plant nitrogen accumulates in the seed at maturity, most of the fixed nitrogen is removed from the soil with the harvest of the seeds of pulse crops. Although residues from pulses are low in quantity, their nitrogen content is much higher than in cereal straw and they break down more quickly releasing nitrogen to the soil. As shown in Table 4, the residues of three common grain legumes increase the available nitrogen by different amounts. Consequently, subsequent cereal crops require proportionately less fertilizer nitrogen.

Table 4 Increase of Available Nitrogen in Dark Brown Soils by Residues from One Crop of Grain Legumes

	Nitrogen	
	kg/ha	(lb/ac)
Lentils	10	9
Peas	25	22
Fababeans	40	36

Source: A.E. Slinkard, Crop Development Centre, Saskatoon

Table 5 Yield of Dry Matter and Nitrogen from Tops and Roots of Sweetclover, Alfalfa, and Red Clover on Degraded Black Loam at White Fox

Growth stage and date of sampling	Legume	D.M. kg/ha (lb/ac)			N. kg/ha (lb/ac)		
		Tops	Roots	Total	Tops	Roots	Total
Second year							
Early bud	Sweetclover	2280(2029)	620(552)	2900(2581)	66(59)	10(9)	76(68)
(June 15)	Alfalfa	2280(2029)	930(828)	3210(2857)	66(59)	16(14)	82(73)
	Red clover	1830(1629)	720(641)	2550(2270)	49(44)	13(12)	62(55)
Full bloom	Sweetclover	4830(4299)	910(810)	5740(5109)	83(74)	11(10)	94(84)
(July 15)	Alfalfa	3700(3293)	1560(1388)	5260(4681)	71(63)	30(27)	101(90)
	Red clover	3390(3017)	1020(908)	4410(3925)	62(55)	19(17)	81(72)

Source: K.E Bowren *et al.* Can. J. Plant Sci. Vol. 49:61-68 (1969)

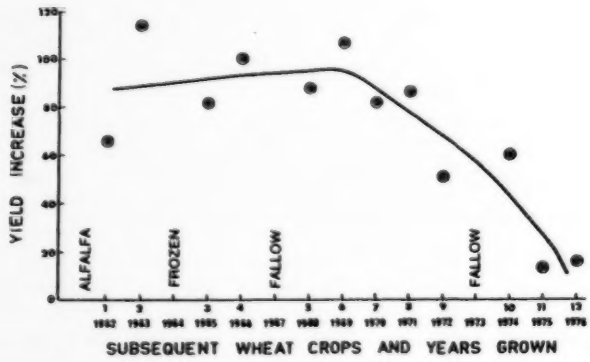
Forage legumes are much more effective in improving soil quality because of their large and deep root system, longer growth period and greater capacity for N_2 - fixation. In more humid regions, such as Northeastern Saskatchewan, biennial and perennial legumes can produce large quantities of organic matter and nitrogen in the second year after underseeding to cereals (Table 5). For maximum soil improvement, forage legumes should be managed as green manure with the entire growth being turned under prior to full bloom.

The data in Table 5 indicate that, when top growth is harvested for hay or silage and only the stubble is turned under, less than one-third of the legume dry matter and nitrogen is retained by the soil. However, even when legumes are used for hay or silage the beneficial effects on soil quality and following crops may be substantial on some soils.

On degraded soils with typically low organic matter contents, regular green manuring with forage legumes has been found to increase soil nitrogen and organic matter over extended periods. The growing of legumes on a Grey soil in Northern Alberta increased the yield of 12 successive wheat crops over that of wheat in a non-legume rotation (Figure 4). In a fertile Black soil, regular manuring with legumes did not prevent the continuous loss of soil nitrogen and organic matter but, as shown in Figure 5, it reduced the rate of loss and maintained total nitrogen at a significantly higher level than in the nonlegume green manured treatment and in the unmanured control soil.

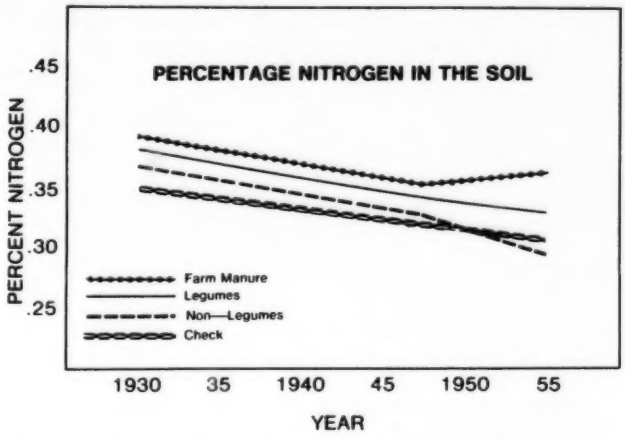
The main effect of turning under forage legumes is to add nitrogen-rich, readily decomposable plant material to the small mineralizeable portion of soil organic matter. This portion is most active in continually supplying mineral nitrogen, phosphorus and sulfur.

Figure 4 *Yield Increase (%) of Continuous Wheat after Alfalfa Compared to Continuous Wheat after Fallow.*



Source: P.B. Hoyt, Agriculture Canada Research Station, Beaverlodge (now at Summerland Research Station)

Figure 5: *Effect of Farm and Green Manures on Nitrogen Content of a Black Clay Soil in Manitoba*



Source: E.A. Poyser *et al.*, Can. J. Soil Sci., Vol. 37:48-56 (1957)

Thus, not only nitrogen but also more phosphorus is made available to subsequent crops.

Deep-rooted legumes tend to bring up phosphorus from the subsoil and the turning under of fresh legumes greatly stimulates the activity of soil microbes which, in turn, speeds up the cycling of nutrient elements and increases the release of plant-available nutrients from soil organic reserves.

The increase in "active" soil organic matter and microbial life also improves soil structure by binding more soil particles together into aggregates and forming more pore spaces. As a result, the soil becomes more friable and less erosive, is easier to till and can hold more water.

Studies carried out on several soils in Saskatchewan have shown that power requirements for tillage were significantly lower on soils following a perennial legume crop than after cereal grains (Table 6). In practical terms this would mean lower energy requirements for tillage operations.

Soil surface crusting can reduce emergence of crops on certain soils. Studies have shown that soils with low organic matter content can develop strong surface crusts, and that emergence of seedlings of crops such as canola is related to crust strength. This problem is seldom encountered on soils with high levels of organic matter.

Forage legumes can arrest developing salinity problems and may even help to correct them. Alfalfa, with its deep roots and high water consumption, can effectively use excess water in saline seeps.

Penetration by roots of perennial legumes will also improve the internal soil drainage. The ability of crops to tolerate salt is enhanced on soils high in organic matter. Maximum organic matter incorporation is more

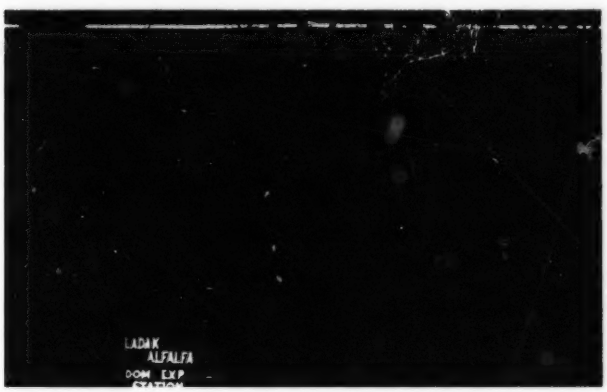
important than the nitrogen supply on saline soils, where soil structure or tilth improvement is the primary concern.

Table 6: Power Requirements for Tillage of Soils With and Without Legumes in Their Crop Rotation [measured to a depth of 15 cm (6 inches)]

Location	Legume	No Legume
	Power Requirement (Newtons)	
Ag. Canada Res. Stn.		
Scott	619	957
Loon Lake	428	768
Melfort	2123	2837
Indian Head*	1130	1016

* Difference Not Significant

Source: M. Grevers and E. deJong - Second Annual Western Provincial Conference on Rationalization of Water and Soil Research and Management, Saskatoon (1983).



Deeply Penetrating Alfalfa Roots. (Depth in metres)

Effect of Legumes on Subsequent Production

A study at Outlook with irrigated alfalfa plowed-down in late fall or early spring indicated that the following cereal crop required little nitrogen fertilizer, while the second cereal crop required two-thirds of its usual amount (Table 7). Although not indicated in the table, the third cereal crop would require the full recommended rate of nitrogen.

Biennial legumes, like sweetclover, can also markedly increase grain production. In a long-term experiment on thin Black soil at Indian Head, wheat yields in a 3-year rotation with sweetclover were consistently higher than in a comparable check rotation and the same as a similar rotation using commercial fertilizer (Table 8).

Annual legumes that are capable of fixing large amounts of N_2 under good moisture conditions can greatly improve the nitrogen supply for succeeding crops. Recent experiments with fababeans in Alberta have shown that even after the top growth was harvested for silage, the residues of this annual legume still provided between 45 and 100 kg/ha (40 and 89 lb/ac) of N to soils for use by a subsequent barley crop. This produced a yield increase of 1350 kg/ha (1202 lb/ac) of grain compared to barley grown on cereal stubble (Table 9).

Management of Legumes for Soil Improvement

Legumes fix atmospheric nitrogen, and their high nitrogen content makes them very desirable for soil enrichment. The amount of organic matter and nitrogen added to the soil by the legume will depend on the amount of growth produced (total dry matter), age or stage of crop, and type of legume. As a green

Table 7 The Effect of Alfalfa on N-Fertilizer Response of Subsequent Cereals under Irrigation at Outlook, Saskatchewan.

Fertilizer N kg/ha (lb/ac)	Yield kg/ha (lb/ac)		
	Before Alfalfa	After Alfalfa	
	1972 Barley	1979 Wheat	1980 Oats
0 (0)	645 (574)	3965 (3529)	3618 (3220)
56 (50)	2043 (1818)	4502 (4007)	4493 (3999)
112 (100)	3118 (2775)	4435 (3947)	5103 (4542)
224 (200)	4301 (3828)	4637 (4127)	5484 (4881)

Source: J.L. Henry, University of Saskatchewan, Saskatoon.

Table 8: Effect of Sweetclover Green Manuring on Wheat Yields at Indian Head, Saskatchewan

Rotation and treatment	17 Year (1960-1976) Average, kg/ha (lb/ac)	
	1st Year Wheat	2nd Year Wheat
Wheat, wheat, clover-fallow	2529 (2251)	2599 (2313)
Wheat, wheat, fallow	2248 (2001)	1171 (1042)
Wheat[1], wheat[2], fallow (fertilized)	2544 (2264)	1662 (1479)

[1] Fertilized with 56 kg/ha (50 lb/ac) of 11-48-0
[2] Fertilized with 90 kg/ha (80 lb/ac) of 23-23-0

Source: R. McIver, Proc. Conf. on Practical Alternatives to Chemicals in Agriculture, Fort Qu'Appelle - 1978.

Table 9 Effect of Fababeans on Yield and Quality of a Following Barley Crop at Lac La Biche, Alberta

1977 Crop	Fertilizer applied 1978*	1978 Barley grain	
		Yield kg/ha (lb/ac)	Protein (%)
Barley	0	1077 (959)	11.3
Fababean	0	2423 (2156)	11.0
Barley	NPKS	2908 (2588)	11.9
Fababean	NPKS	3285 (2924)	13.7

* N, P_2O_5, K_2O and S was applied at 58, 34, 11 and 54 kg/ha (52, 30, 10 and 48 lb/ac), respectively.

Source: R.H. Leitch, Proc. Alta. Soil Sci. Workshop, 331-334 (1979)

manure, the maximum amount of nitrogen and organic matter will be incorporated with maximum above-ground growth.

Legumes **do not** add any nutrient elements to the soil other than nitrogen. If the tops of the legumes are removed as hay, legumes deplete the soil of certain nutrients, and therefore adequate fertilization with phosphorus, potassium and sulphur is important for rapid growth and high yields. If nitrogen fixation by the legume is not effective even nitrogen may be depleted from the soil. Therefore, to maximize production of the particular legume crop, the following conditions should be provided:

- Inoculate seed properly with efficient strains of N_2-fixing bacteria and follow recommendations for seeding.
- Where soil nutrient deficiencies occur, apply adequate fertilizer nutrients such as P, K, S, to promote vigorous growth and high yields of dry matter and good N_2-fixation.
- Control weeds and insects in the legume crop.
- Use snow water conservation practices that will enable the crop to make use of this source of moisture.

Limitations to Use of Legumes for Soil Improvement

In the Brown and Dark Brown soil zones, legumes are seldom included in the typically short crop rotations under dryland conditions. In this semi-arid region, legume growth is usually poor due to early season moisture deficiencies. Nitrogen fixation is also reduced under dry conditions. Even in years of good growth of alfalfa and sweetclover, the depletion of soil moisture by these legumes may result in severe moisture deficits for following grain crops. Thus, perennial legumes have been found to depress the yield of subsequent wheat crops for several years. If the legume is used as a green manure crop, the dry soil conditions may slow down decomposition of the incorporated plant material.

The excessive moisture depletion caused by deep-rooted legumes could be avoided if they were managed as short-term green manures, but perennial legumes produce very little during the first year in the Brown soil zone and would contribute only 10 to 20 kg/ha (9 to 18 lb/ac) of N if incorporated. Consequently, there is little hope for improving the N-supplying power of the drier Brown and Dark Brown soils by means of legumes in the rotation unless highly efficient snow conservation practices can be found and adopted, and more drought-resistant and high N_2-fixing annual legumes can be found for use as "fallow-substitute green manures". Such annual legumes will have to be used in combination with new methods for snow trapping to increase soil moisture reserves. If grass or tall stubble trap strips can capture most of the 30% of precipitation that falls as snow, then more water use-efficient annual legumes may well earn a place in future farming systems in Southern Saskatchewan.

Legume Choice and Management

Annual, biennial and perennial legumes are available as green manuring crops. The choice is a management decision. Consideration should be given to length of rotation, alternative use of the forage, soil type, expected annual precipitation and cost of establishment.

Perennial legumes have a life span of several years and may be used as a source of hay or pasture before plow-down. A grower may choose from one of several legumes.

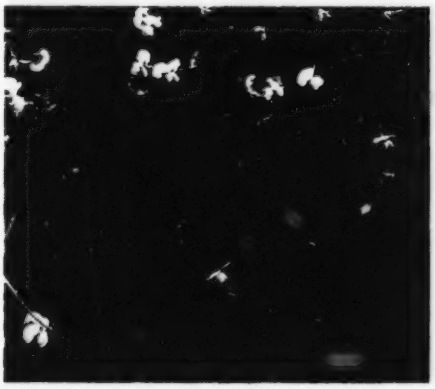
Alfalfa is a widely adapted high yielding forage legume. It has good drought tolerance, moderate salinity and flooding tolerance and is winter hardy. Alfalfa will yield 1500-2500 kg/ha (1335-2225 lb/ac) per cut and two or more cuts are available when moisture supply is good. **Sainfoin** and **birdsfoot trefoil** are bloat-free alternatives. Sainfoin is short-lived and not very drought tolerant. Seed costs are generally high. Birdsfoot trefoil is lower yielding than alfalfa and not widely grown in Saskatchewan. **Alsike** or **red clover** are best suited to the park belt but will produce less dry matter than alfalfa. **Sweetclover** is a biennial which is established (often with a companion crop) the first year and turned under the following year. It is drought tolerant and high yielding but the whole crop should be used to obtain the greatest advantage as a green manure. Sweetclover weevil is a serious pest and may have to be sprayed. Water use is also high if the clover is not turned under at the early bloom stage.

Two annual legumes may be considered for green manure only if inexpensive seed is available. Field peas and fababeans are best adapted to the parkbelt. They are sown early and turned under at the early bloom stage.

Annual Legumes

Annual legume crops currently used for grain, hay or silage may also be used as potential sources of nitrogen or as green manure crops. These crops include field peas, lentils and fababeans, all of which are currently grown commercially. Normally it is too expensive to incorporate these crops as green manure. Other annual legumes include fields beans, soybeans, chickpeas and flat peas, but these are not grown extensively at the present time. The potential of these crops under our conditions is not known.

In an extended cropping system, annual legumes will provide nitrogen for the succeeding crop.
The yield and protein content of grain and plant residue from some annuals grown at Melfort are shown in Table 10.
Legumes are also a break-crop for the control of insects and diseases in cereal crops, and are cash crops which can provide cash flow advantages.



Peas

Lentils

Agronomic Practices

A. Seeding Date

Most annual legumes are fairly tolerant to early spring frost and therefore should be seeded as early as possible. Table 11 gives the approximate seeding rates and depths for the annual legume crops currently grown. This rate and depth depends on seed size; thus a range is shown for each crop.
Within this range these legumes should be seeded no deeper than necessary to reach adequate moisture for germination.

B. Fertility Requirements

Good soil fertility is important for maximum nitrogen fixation. Nutrients that can be limiting, particularily phosphorus and sulphur, must be supplied in suitable form and in adequate amounts for the legume. Sulphur is important for legumes and may be required on Grey Wooded soils and other light textured soils in northern areas. Excess nitrogen can limit the amount of fixation. Legumes will preferentially use available nitrogen from the soil rather than fix nitrogen when the level of available soil nitrogen is high [greater than 50 kg/ha (45 lb/ac)]. However, on soils with very low levels of nitrogen the addition of 15-20 kg/ha (13-18 lb/ac) can boost seedling growth prior to the establishment of effective nodules. For further information on fertilizer use refer to Publication "Saskatchewan Fertilizer Practices".

C. Weed Control

Refer to Weed Control Bulletin in the Appendix.

Biennial Legumes

The only biennial legume grown on the Canadian prairies is sweetclover. Sweetclover is an upright, broadleaved legume with many stems and branches. In the seeding year plants develop to a height of 30-90 cm (12-36 in). In the second year flowers are produced and the crop grows 1.2-1.5 m (4-5 ft) tall at maturity. There are two common types: yellow-flowered and white-flowered.

Table 10 Yield and Nitrogen Content of Grain and Straw of Fababeans and Peas at Melfort, Saskatchewan

	Grain		Straw**		
Crop	Yield Kg/ha (lb/ac)	Protein Content %	Yield kg/ha (lb/ac)	Protein Content %	Nitrogen Content kg/ha (lb/ac)
Fababeans	2551 (2270)	26	1963 (1747)	10.0	26.5 (23.6)
Field Peas	3011 (2680)	22	2136 (1901)	9.0	26.2 (23.3)
Fababeans & Peas*	3016 (2684)	24	1841 (1638)	10.3	24.9 (22.2)

* Fababeans and field peas growing together. Seeded at right angles in 36 cm (15 inch) spaced rows.
** The roots, stubble and some chaff remained in the field.

Source: K.E. Bowren

Table 11 Seeding Practices for Annual Legumes.

Annual Legumes	Seeding Depth cm	Seeding Depth in	Seeding Rate kg/ha or (lb/ac)
Peas	3-8	1-3	125-190 (111-169)
Fababeans	7	3	150-175 (134-156)
Lentils	3-8	1-3	35-80 (31-71)

Source: *Dry Pea Production in Saskatchewan*, University of Saskatchewan, (1984)
Guide to Farm Practice in Saskatchewan, (1984)
Legume Production in Western Canada, University of Saskatchewan, (1984)

Yellow & White Blossom Sweetclover

Choice of Varieties

The yellow-flowered type is preferred by farmers. It is more drought-resistant, shorter, finer stemmed, finer leaved and flowers earlier than the white-flowered type. These characteristics make it a more palatable livestock feed. The taller, coarser stemmed growth of the white-flowered type makes it more difficult to incorporate as green manure. The yellow-flowered type grows more rapidly early in the spring and can be harvested or incorporated earlier. This allows a longer period for recovery of soil moisture reserves. Where the crop is grown for feed, the newly-licenced variety Norgold should be grown. Norgold is a yellow-flowered variety that produces forage with a low coumarin content. Low coumarin sweetclover poses no danger of causing "sweetclover or bleeding disease" of livestock. Norgold is much higher yielding than the white-flowered, low coumarin variety Polara. Yukon, a high coumarin yellow-flowered variety is suitable where the crop is grown only for green manure. Yukon has a small advantage in yield and vigor over Norgold.

Seeding

Sweetclover and most other forage legumes have small seeds, thus they will only emerge from shallow depths (less than 2.5 cm or 1 inch) in the soil. Preseeding tillage should be done as shallow as possible to conserve moisture near the surface and provide a firm seedbed. Economic conditions in Saskatchewan dictate that most forage legumes are seeded with a companion crop. The seeding rate of the companion crop should be reduced to half or less of the normal rate. The companion crop should be sown first and the soil firmed with harrows and/or packers. The forage legume should then be sown, preferably at right angles to the companion crop rows to reduce competition. The legume should be sown within a few days of the companion crop to improve its ability to compete and survive with the companion crop.

Cereals are the most suitable companion crops. Limited research with canola indicates that poor stands result, probably due to shading by the large canola leaves. Use of flax as a companion crop usually results in weedy stands as flax is not very competitive. Barley is quite competitive with forage legumes, however it matures earlier than other spring cereals. As a result the legume has an opportunity to become established after harvest. Barley is most suitable in the Black and Grey Wooded soil zones where fall rains are usually adequate for fall growth of the legume. Wheat and oats are less competitive and later maturing than barley. They are more useful as companion crops in the Brown and Dark Brown soil zones where rainfall is frequently inadequate for significant fall growth. Where the companion crop can be used as green feed, oats is preferred. Early removal of the companion crop as forage is often beneficial for establishment of a forage legume, particularly if the crop is weedy or suffers from drought.

Seed sweetclover as early as possible in the spring. Early seeding takes advantage of favorable moisture conditions and allows the sweetclover seedlings to emerge and become established before weed growth begins. **Fall seeding of sweetclover is not recommended.** Inoculate the seed immediately prior to seeding with the proper inoculant to ensure optimum N_2-fixation.

Sweetclover has a hard seed coat and must be scarified before seeding. Seed companies sell only scarified sweetclover seed. Sweetclover can be scarified with a grain crusher by adjusting the plates so that only the seed coat is cracked.

Weed Control and Fertilizers

Cultural practices are required for broadleaf weed control as no herbicides are licenced for this purpose

in sweetclover. Production of sweetclover should be planned well in advance to minimize weed populations prior to seeding. Several practices which have proven useful in reducing weed populations and competition are as follows:

- reduce weed populations in preceding crops through selection of crops and herbicide use.
- treat stubble land the preceding fall for control of winter annuals.
- seed relatively weed-free fields.
- conserve moisture with shallow pre-seeding tillage.
- seed as early as possible in the spring, immediately after pre-seeding tillage.

An alternate method for use on stubble where winter annuals have been controlled with a herbicide is to use a herbicide to "burn off" weeds present at the time of seeding and to seed the companion crop and then the sweetclover directly into the undisturbed stubble.

Where wild oats and green foxtail are a problem they can be controlled with herbicides. The selection of herbicides to use must be such that it is compatible with both the companion crop and sweetclover. Current information is contained in provincial bulletins on chemical weed control.

Fertilizer applications should be based upon results of soil tests. Where required, phosphorus, potassium and sulphur should be applied. Proper use of fertilizer aids in establishment of vigorous competitive stands of sweetclover, and may contribute to increased yields of succeeding crops. Sulphur deficiency can severely depress sweetclover growth. Because the crop is a biennial, some consideration should be given to supplying enough of these nutrients to meet the second year needs of this crop. Sweetclover obtains its nitrogen requirements by nitrogen fixation in the root nodules. Where the crop is grown on stubble with a companion crop, it may be desirable to use some nitrogen fertilizer for the companion crop. High rates of nitrogen should be avoided, as this will reduce nitrogen fixation by the root nodules.

The sweetclover weevil can cause significant damage to this crop. This pest will likely become more abundant wherever sweetclover acreage is increased. For recommended control measures consult bulletin on Insect Control in Forage Crops in Appendix.

Crop Uses

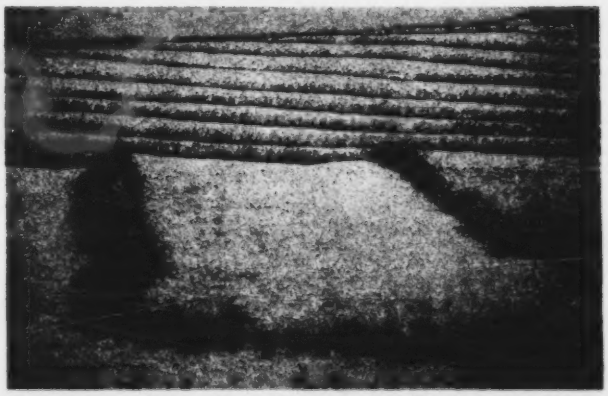
Sweetclover is one of the most suitable crops for use as a green manure. In the second year it grows rapidly and can be incorporated early. Incorporation should be done at the bud stage, as most of the N fixation has occurred by this time (Table 5 and Figure 6). This allows time for recovery of soil moisture reserves and residue decomposition during the partial fallow period. Later incorporation should only be considered in cases where it is desirable to incorporate the maximum amount of organic matter. Examples of such cases are on moderately saline soils or soils that have poor structure due to very low levels of organic matter. However, excessive moisture depletion by later growth may result in slow decomposition of the added organic matter and low moisture reserved for the succeeding crop.

Sweetclover has a deep tap root which opens the subsoil and utilizes nutrients from deep in the soil profile. This can improve moisture storage where the subsoil is relatively dense. Nutrients in the sweetclover are released during decomposition and become available to crops which do not root as deeply. A properly inoculated sweetclover crop returns large quantities of nitrogen to the soil. Generally about one-half of this nitrogen is available to the succeeding crop.

Swathing Sweetclover in the Parkland.

Sweetclover has been shown to be most beneficial on Grey Wooded soils. Where sweetclover is grown as a regular part of rotations on such soils, succeeding grain crop yields are similar whether the crop is used as forage or as a green manure. Where it is grown less frequently it may be more valuable as green manure than as hay. Where it is used as hay, care in harvesting is required to minimize leaf losses. Use as silage reduces leaf losses and cutting can be delayed without reducing forage quality. Where sufficient growth occurs sweetclover may be harvested in late September of the first year without reducing second year yields.

Sweetclover production for seed usually increases the cash value of the crop. However, seed prices can fluctuate widely from year to year. Sweetclover grown for seed reduces moisture available to succeeding crops, compared with use as green manure or forage. Soil moisture recovery can be enhanced by leaving stubble as tall as possible or by leaving strips of standing crop to trap snow.



Sweetclover Snow Trap Strips in the Southern Prairies.

Much of the nitrogen from the crop is removed with the seed, therefore reducing the amount available to succeeding crops.

Rotations

Sweetclover fits well into short rotations with crops because it is a biennial. It is best adapted to use on problem soils such as degraded soils low in organic matter, soils where crusting is a problem or on saline soils. In many cases it fits well into rotations as a substitute for summerfallow.

A cereal crop should be grown following sweetclover. Oilseeds do not respond as well as cereals when grown immediately after sweetclover. When grown as a second crop after sweetclover, oilseeds frequently show yield responses on degraded, low organic matter soils or those that crust.

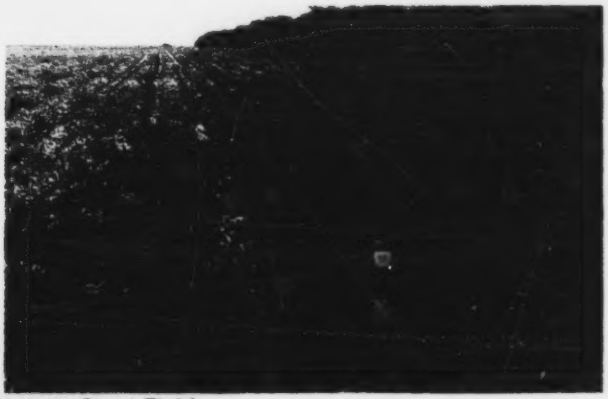
Sweetclover may be substituted for fallow on more productive soils. Most soils will benefit from the additional organic matter and nitrogen added. However, it is difficult to document yield responses by crops following sweetclover on such soils. Frequently yield depression occurs in crops following sweetclover compared to those grown on fallow. This is particularly so in drier areas and in dry years. Such losses may be recovered in improved yields in other years of the rotation or reduced costs for nitrogen fertilizers.

Perennial Legumes

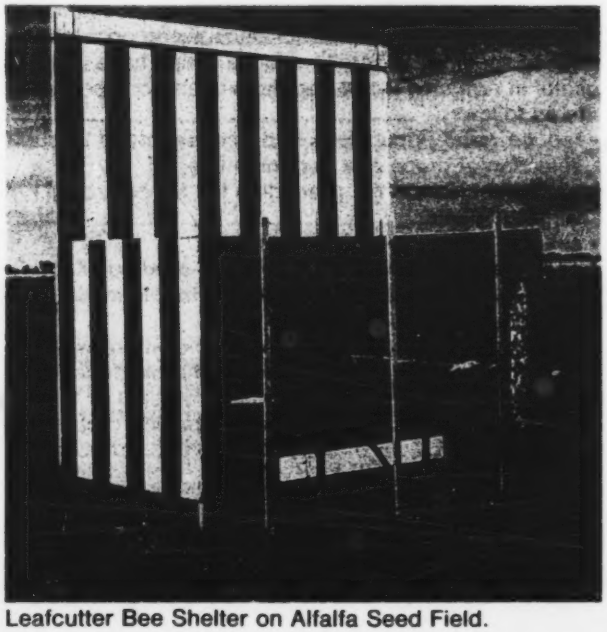
When perennial legumes are grown in rotation they will fix nitrogen and add humus and nutrients to the soil. Alfalfa is the main perennial legume grown in Western Canada. It is grown for hay, seed and in some areas as a major crop for the alfalfa dehy industry. Red clover is another commonly grown perennial legume. It is shorter lived than alfalfa and thus fits well into short term rotations. It is adapted to a wide range of soils in the moister areas of the province. It is more tolerant to acidic soils than is alfalfa or sweetclover. It is grown for feed and for seed.

Alsike clover is produced to a limited extent in Saskatchewan. It is a short lived perennial that is adapted to low lying moist areas. It will stand considerable spring flooding and has the capacity to propagate itself from shattered seed or root sections. It is well suited to acidic organic soils.

The main varieties of perennial legumes, seeding practices, and weed control, are discussed in the provincial forage crop recommendation publications.



Alfalfa Seed Field.



Leafcutter Bee Shelter on Alfalfa Seed Field.

Redclover Seed Field in the Parkland.

Seeding

To establish a good stand, perennial legumes should be inoculated and seeded shallow, 1-2 cm (½-¾ in) deep, into a firm seedbed. Perennial legumes can be seeded in the spring until the end of July or in fall just prior to freeze-up (after mid-October).

In spring seeding, the legumes will usually be seeded with a companion crop of grain and often in mixtures with grass. They should be seeded in a separate operation from the companion crop unless the legume crop can be seeded less than 2 cm (¾ in) deep.

For best results the legume should be seeded with a press drill at right angles to the companion crop. In the fall, the legume should be seeded into standing stubble at a shallow depth on firm, moist soil.

Weed Control and Fertilizers

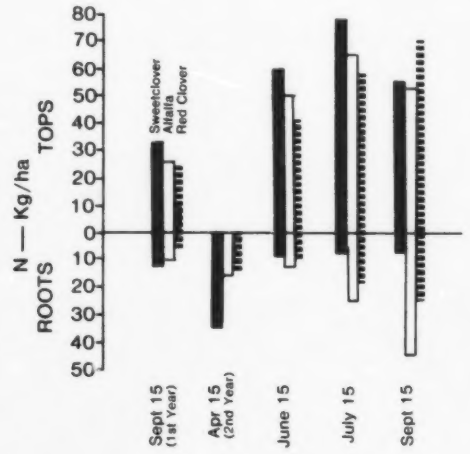
The land where perennial legumes are to be seeded should be relatively weed-free but weeds can be controlled with herbicides in both the seedling and established stands (refer to Weed Control in Crops, Saskatchewan Agriculture). The fertilizer used with the legume should be based on soil tests and expected production requirements. The production of 4 tonnes per hectare (3563 lb/ac) of alfalfa, for example, will use about 280 kg/ha (250 lb/ac) of nitrogen, 45 kg/ha (40 lb/ac) of phosphate (P_2O_5), 193 kg/ha (172 lb/ac) of potash (K_2O), and 22 kg/ha (20 lb/ac) of sulphur. Alfalfa is particularly sensitive to sulphur deficiency.

Sulphur Deficiency in Red Clover on Grey Soil.

Narrow-Leafed Hawk's-Beard Infestation Indicates Sulphur Deficiency in Alfalfa.

If adequately inoculated, the legume will fix nitrogen. Alfalfa will accumulate about 100 kg/ha (89 lb/ac) of nitrogen by the bloom stage of the second year's growth. In a 5 year study at Melfort and White Fox, alfalfa, on average, accumulated 38, 16, 62, 95 and 98 kg/ha (34, 14, 55, 85 and 87 lb/ac) of nitrogen at the end of the first season's growth, the early spring, bud stage, the full bloom stage, and at the seed harvest stage of the second year respectively. In contrast to sweetclover, alfalfa and red clover had a greater proportion of nitrogen stored in the roots in the second year: removing a crop still provided for a

Figure 6: *Average Nitrogen (kg/ha) in Tops and Roots of Three Legumes at Five Growth Stages on Black and Degraded Black Soils of Northeastern Saskatchewan*



Source: Bowren et al. Can. J. Plant Sci. Vol. 49:61-68 (1969)

substantial amount of nitrogen to be returned to the soil (Figure 6).

In addition to the nitrogen, perennial legumes add a considerable amount of organic matter to the soil. At Melfort, by the bloom stage in the year after seeding, alfalfa had accumulated 1596 kg/ha (1420 lb/ac) of dry matter in the top 25 cm (10 in) of soil. The roots contained 28 kg/ha (25 lb/ac) of nitrogen. At White Fox comparable figures were 1562 and 30 kg/ha (1390 and 27 lb/ac) at the bloom stage of the second year's growth. In addition, the roots of alfalfa may extend downward 3 m (10 ft) or more and thus affect the organic matter and the recycling of nutrients to that level.

Over a 24-year period from 1956 to 1982, growing an alfalfa-grass mixture for 2 years in a 6-year cereal forage rotation increased the yield of grain on fallow and stubble by 8% and 15% respectively, at Somme on Grey-Black soil, but by less than 1% at Melfort on Black soil. The amount of nitrate-nitrogen in the soil in fall was increased by 38% on fallow and by 51% on stubble at Somme where the alfalfa-grass mixture was included in the rotation. At Melfort the increases were 25% on fallow and 45% on stubble compared to a straight grain cropping sequence. The protein content of grain grown in the grain-forage rotation was about one percentage point higher than the protein of grain produced in a straight grain cropping sequence. Other stations report similar effects of growing legumes in rotations. Due to the cost of seeding perennial legumes, they fit best in rotations where they can be left down for three or more years and utilized for hay, seed, or alfalfa dehy. They are seldom used as a short term plow down crop. When utilized for hay, seed, or dehy they can be a profitable crop that will improve the productive capacity of the soil. Substantial benefit will result if properly fertilized perennial legumes are grown on degraded soils low in organic matter and on

soils that tend to crust. If the total top-growth of the crop is removed, however, about half the nitrogen fixed will be removed from the field. In that case, succeeding crops may require additional nitrogen fertilizer for adequate production.

In breaking a legume stand that has been down a few years, under dryland conditions, several weeks should be allowed for a partial fallow to kill the legume plants, decompose the sod and replenish the soil moisture reserves for the succeeding crop. The residue of red and alsike clover breaks down quicker and the field is somewhat easier to restore to a suitable state for cereal production than is an alfalfa stand.

Dehy Plant for Pelleting Alfalfa.

On irrigated land at Outlook, the University of Saskatchewan found that growing a pure stand of alfalfa for four years added a considerable amount of nitrogen to the soil that would affect the first 2 crops after breaking (Table 7). With irrigation, moisture is not a critical factor in future cropping and thus alfalfa could be broken in fall and seeded to an irrigated grain crop the following year.

Legume Inoculation

Inoculation refers to the introduction of *Rhizobium* bacteria into the soil so that root hairs of seedlings will form nodules (Figure 3) that enable the legume to fix atmospheric nitrogen. The term 'nodulation' is used to describe nodule formation.

Need for Inoculation

Many soils lack sufficient numbers of the specific rhizobia needed for growth and high yields of forage and grain legumes. The rhizobia that can nodulate alfalfa and clovers do occur naturally in most Prairie soils. However, some strains of the native soil population infect the roots but are not able to fix nitrogen while other native strains do fix nitrogen but often not as efficiently as the specially selected strains used in commercial inoculants. Inoculation corrects those deficiencies by sticking thousands of highly effective N_2-fixing rhizobia to each seed immediately before planting.

Legume growers should look upon the practice of seed inoculation as being a very economical and effective form of crop insurance against yield reduction due to shortage of nitrogen (Table 3). There are numerous reasons for inoculating legumes:

- It ensures early formation of effective nodules for N_2-fixation.
- It makes sufficient nitrogen for vigorous growth available to the seedling soon after the seed protein supply is exhausted.
- Many soils are devoid of the species of rhizobia needed for effective nodulation of grain legumes and some contain rhizobia with low fixation efficiency on forage legumes.
- Without inoculation or heavy N-fertilization, legumes will not produce well on these soils.
- Proper inoculation often increases legume yield by more than 100% on soils that are low in nitrogen (e.g., sandy cereal stubble fields) and lack sufficient numbers of effective rhizobia.
- In grass-legume mixtures, roots of grass intermingle with legume roots and can use some nitrogen fixed in nodules to boost grass yields (Figure 7).
- Inoculation improves the nutritional value of legumes because it usually results in a small increase in the protein content of grain and forage legumes, particularly when they are grown on less fertile soils.

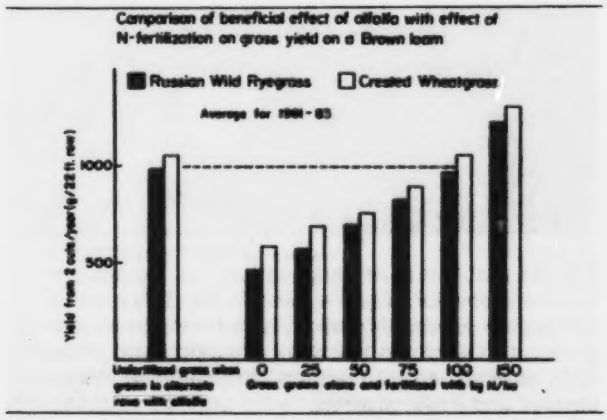
Effect of Inoculation on Growth of 3 week old Legume Seedlings (Note Inoculated Pouch on the Right)

Alfalfa

Red Clover

Effect of Inoculation on 4 week old Peas.

Figure 7: *Relative Fertilizer Benefit of Alfalfa on Grass Yield on a Brown Loam*



Source: A.J. Leyshon, Agriculture Canada Research Station, Swift Current

Inoculant Types and Quality

An inoculant is made up of one or more strains of a *Rhizobium* species in a carrier material that supports and protects the live bacteria. The most common carrier is finely-ground peat moss with some lime added to prevent acidity. The peat has a very high water-holding and buffering capacity which protects the rhizobia against unfavorable soil conditions.

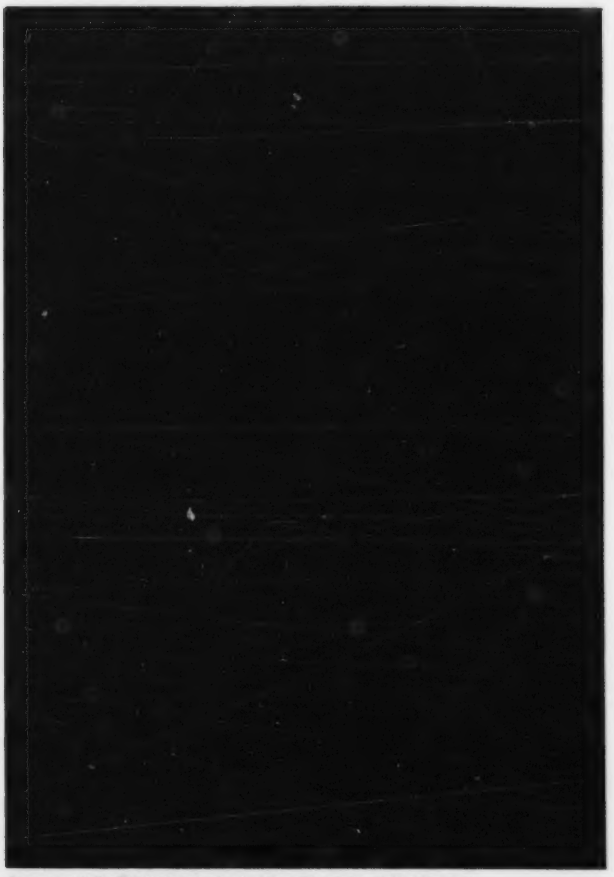
Two types of inoculant products are sold in Canada for farm use:

1) *Powdered Inoculant* - a fine peat or clay that contains over a billion infective rhizobia per gram and must be applied directly to the seed; and
2) *Granular Inoculant* - small granules, the size of soil herbicide pellets, that contain as many rhizobia as the powdered inoculant but are designed to be applied in the furrow with the seed. This new type is used mainly for inoculation of grain legumes. Compared to peat-based inoculant the granular form is more convenient to use and seems to be more effective in dry soils, but on a per acre basis it is also much more costly than the traditional powdered form.

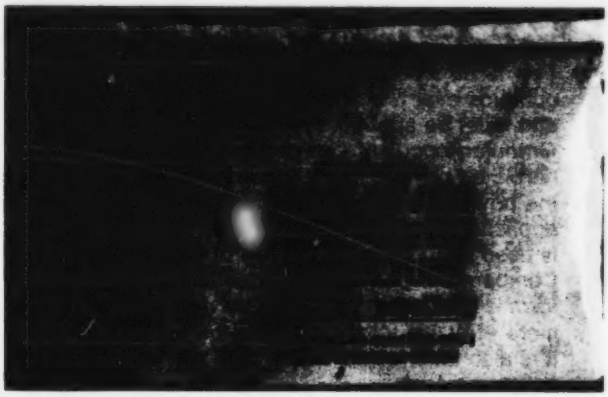
All legume inoculants sold in Canada are registered under the Fertilizers Act administered by Agriculture Canada. Inoculant products are regularly sampled by federal inspectors and tested by analysts from Agriculture Canada to ensure that they meet rigid quality standards. The development and enforcement of this control program has produced a marked improvement in the quality of commercial inoculants being marketed in Canada as shown in Figure 8.

The inoculant package label contains the following information: legume types the inoculant is suitable for;

Figure 8: *Improvement in Performance of Inoculant Products since the Start of Federal Testing for Quality Control*



Source: V.O. Biederbeck, Agriculture Canada, Swift Current



Inoculant Label must State Expiry Date.

Preparing Sticker Solution.

name (species) of *Rhizobium* bacterium; quantity of seeds the package will inoculate; federal registration number; expiry date; and directions for methods of application. This ensures that good nodulation and nitrogen fixation will result if the inoculant is properly stored and correctly applied to the seed. Inoculants are live cultures of bacteria and should be kept refrigerated or at least cool, avoiding dryness and the harmful rays of the sun.

There are several species of *Rhizobium* bacteria. For example, the species that nodulates alfalfa and sweetclover will not function on the clovers, nor on peas, lentils, beans, and other legumes. Thus each legume or group of legumes requires a unique species of *Rhizobium* (R.) to form nodules and fix nitrogen. The commercial inoculants available are prepared for specific legumes and groups of similar legumes:

• alfalfa group	- *R. meliloti* for alfalfa and sweetclover.
• clover group	- *R. trifolii* for red clover, white clover and alsike clover
• sainfoin	- *Rhizobium* spp. (special strains).
• bird's-foot trefoil	- *R. loti*
• pea and vetch group	- *R. leguminosarum* for field peas, garden peas, flatpeas and common vetch.
• bean group	- *R. phaseoli* for field and garden beans.
• lentils	- *R. leguminosarum* (special strains).
• fababeans	- *R. leguminosarum* (special strains)

Inoculation with the proper inoculant is essential for good nodulation and high N_2-fixation. Some legumes, particularly varieties of peas, have specific rhizobial strain preferences. A strain of *R. leguminosarum* that produces excellent results on one variety may be a poor nitrogen fixer on another variety. To compensate for this type of strain variation commercial inoculants usually contain two to five different strains of one *Rhizobium* species.

Methods of Inoculation

The most common type of inoculant sold for forage and grain legumes is the powdered peat-base inoculant. To be effective the inoculant must adhere to the seed to ensure that the rhizobia are close to the newly-emerging roots. There are two methods for applying powdered inoculants:

Water-Slurry Method — the inoculant is suspended in water and then mixed thoroughly with the seed until each seed is coated uniformly with the inoculant powder. Although water application is preferable to applying dry powder to the seed, it is not as effective as the sticker solution method.

Sticker Solution Method — this is the most effective method because it 'glues' the inoculant to the seed. The adhesive material or inoculant sticker also serves to feed the rhizobia and to protect them from drying conditions on the seed. Several sticker products are available commercially from the companies that manufacture inoculants. Suitable stickers can also be prepared on the farm by making a 10% solution of corn syrup or table sugar or honey in water. Table 12 indicates that powdered milk is also an effective adhesive agent.

The old practice of dry application, i.e., dumping the inoculant powder onto the seed in the drillbox and stirring the seed with a stick, is not recommended because most of the inoculant is wasted and various tests have shown this method of application to be useless and ineffective.

Legume seeds should be placed in a large container (cement mixer, tub, pails) and sufficient sticker applied to slightly wet all seeds. Then half of the required amount of inoculant powder should be sprinkled on the seeds while mixing until the seeds are uniformly black. To eliminate the need for spreading out and drying the inoculated seed and to avoid clogging of the seeder, the other half of the required amount of inoculant powder is then added to the partially inoculated seed and mixed thoroughly in

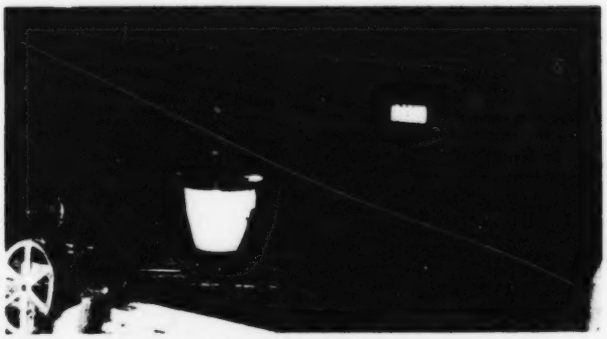
Table 12 — Effect of Adhesive Agents on Yield of King Grain Line X005 Soybeans

Adhesive Agent	Nodules per plant	Plant Yield (mg)
Uninoculated	0	350
Water	39	779
Nitracoat	109	911
Nutrigum	109	961
Pelgel	89	754
Gum Arabic	105	1013
Carboxymethyl cellulose	103	1127
Wallpaper glue (if non-toxic)	128	1226
Sugar	83	751
Corn syrup	88	964
Honey	94	854
Powdered milk	96	1081
Evaporated milk	78	970

Source: M.S. Elegba and R.J. Rennie Can. J. Soil Sci. Vol. 64:631-636 (1984).

the container. The fully inoculated seed can then be planted with normal seeding equipment. This type of seed inoculation may be done one to two days before the actual seeding date but only if the inoculated seeds can be stored in a cool place. Detailed instructions are given on inoculant and sticker package labels.

Large-seed legumes, such as peas or lentils, can be effectively inoculated by applying an inoculant-sticking agent slurry into the auger intake as the seed is being augered. Seed inoculated by this method should be allowed to dry for a few hours in a cool, shaded area prior to seeding.



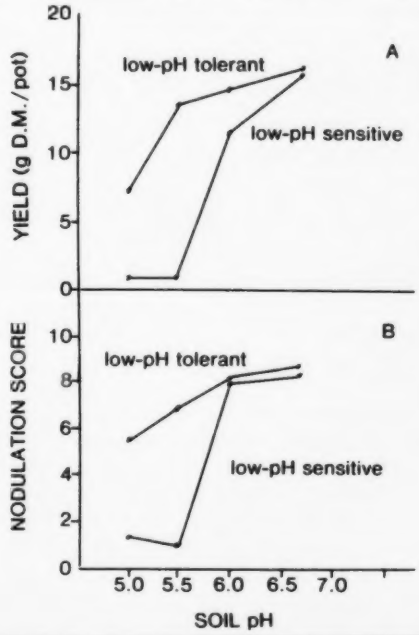
Seed Inoculation with an Auger.

Commercially pre-inoculated forage legume seed is becoming more common on the seed market. It is convenient as its use eliminates the extra time and effort required to apply inoculants on the farm, but it is more expensive and has a major disadvantage in that the viability of rhizobia decreases rapidly once they are applied to the seed. However, the quality of some pre-inoculated seed products, particularly coated seed, is now generally sufficient for adequate nodulation.

The potential for nitrogen fixation is closely related to plant growth factors; thus any condition, stress or management practice that affects plant growth is likely to affect nodulation and N_2-fixation.

Nodulation will be reduced in acid soils because most rhizobia are very sensitive to a pH below 5.5 and may die before nodulating the plants. Lime should be applied before seeding legumes where soil pH is low. Calcium and magnesium are also very important in the nodulation and N_2-fixation processes. Now there are special, commercially available, low-pH tolerant rhizobia strains in the alfalfa group which have been selected and tested in Western Canada for their ability to survive and nodulate in acid soils (Figure 9).

Figure 9: *Yield (a) and Nodulation Score (b) of Alfalfa Inoculated with Low-pH Tolerant and Low-pH Sensitive Strains of R. meliloti.*



0 Worst
10 Best

Source: W.A. Rice, Can. J. Plant Sci. Vol. 62:941-948 (1982)

Applications of fertilizer nitrogen to legumes at rates greater than 30 kg/ha (27 lb/ac) of N can substantially reduce nodule formation and inhibit N_2-fixation. Also, excessive rates of N applied to legume-grass mixtures tend to reduce the legume component because of strong competition from the grass for light, water and nutrients.

Rhizobia do not survive well in dry and in very warm soil. The first few days following planting are the most critical. Drying of the soil surface and/or soil temperatures above 20°C at seeding time will kill many bacteria and greatly decrease legume nodulation. Thus inoculated seed should be sown into a moist seedbed on cool days, if possible.

Chemical Seed Treatments

Legume seed treated with fungicides or insecticides requires special consideration because many chemical seed disinfectants are toxic to rhizobia. However, the fungicide Thiram, used for prevention of Verticillium wilt of alfalfa, has no negative effect on rhizobia

survival. Generally, seed treatments do not seriously harm nodulation if the seed is properly inoculated with a high quality, peat-base inoculant and is planted immediately following inoculation. However, when legume seeds must be treated with pesticides known to be toxic to bacteria then direct inoculation of the seed should be avoided and granular inoculant should be drilled into the seed furrow for massive soil inoculation to provide sufficient rhizobia for subsequent root nodulation.

The use of insecticides and herbicides can also be compatible with the rhizobial inoculation of legumes, but precautions are necessary if the full benefits of biological N_2-fixation are to be realized by producers. Fertilizers should not be allowed to come in direct contact with inoculated legume seeds because the frequently low pH and high ion concentration in the soil solution around the fertilizer granules will kill the rhizobia.

If legumes are being planted under any of the previously mentioned soil or chemical stress conditions it is recommended that 3 to 5 times the usual amount of inoculant be applied.

How to Check for Nitrogen Fixation

To determine if N_2-fixation is occurring, dig (don't pull) the roots of several plants at different spots in a field and examine the crown region for clusters of nodules. Slice open several nodules from each plant and if they are pink to beefsteak-red on the inside then they are effective nodules. The red color is due to leghemoglobin, an iron-containing pigment associated with active N_2-fixation. The number of nodules and the rate of N_2-fixation will increase with time after emergence and normally reaches a maximum just before the legume blooms.

Ineffective rhizobia often produce nodules, but these nodules are small and white, grey or green on the inside. Ineffectively nodulated legumes can normally be recognized by the symptoms of nitrogen deficiency, i.e., progressive yellowing of the leaves and generally poor growth.

Interior of Effective Alfalfa Nodules.

For Effective Nodulation:

- Inoculate all legume seed with the appropriate type of rhizobia.
- Carefully read the label on the inoculant package.
- Store inoculant in a cool dry place until use.
- Use the sticker method of inoculation.
- Inoculate seed just before seeding.
- Do not mix fertilizer with inoculated seed.
- Sow inoculated seed in a moist seedbed.
- Use higher rates of inoculant for adverse conditions.

Table 13 Legume Seed Characteristics

Crop	Botanical Name	Approximate Density		Approximate No. Of Seed Per:		Approximate Seeding Rate		Approximate Germination Time (Days)
		kg/m³	lb/bu.	Gram(No.)	lb.(Thousands)	kg/ha	lb/acre	
Perrenials								
Alfalfa	Medicago sativa	750	60	500	220	4-7	4-6	7
Birdsfoot Trefoil	Lotus corniculatus	735	60	800	375	4-5	4	7
Alsike Clover	Trifolium hybridum	735	60	1500	680	3-4	3-4	7
Red Clover	Trifolium pratense	750	60	600	260	5-7	4-6	7
Sainfoin	Onobrychis viciaefolia	360 (in pod)	30	50	23	30	27	10
Biennials — Sweetclover								
White blossom	Melilotus alba	780	60	570	250	8	7	7
Yellow blossom	Melilotus officinalis	780	60	570	250	8	7	7
Annual Grain Legumes								
Bean	Phaseolus vulgaris	740	60	4	1-2	45-90	40-80	8
Chickpea	Cicer arietinum	—	—	2	1	200	178	7
Field Pea	Pisum sativum	740	60	8	4	125-190	111-169	8
Fababean	Vicia faba	580	47	3	1-2	150-175	134-156	10
Lentil	Lens culinaris	740	60	20	9	35-80	31-71	8

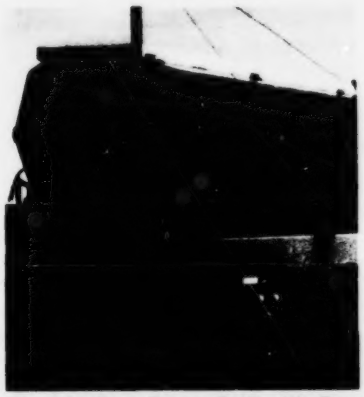
Equipment Requirements

Seeding

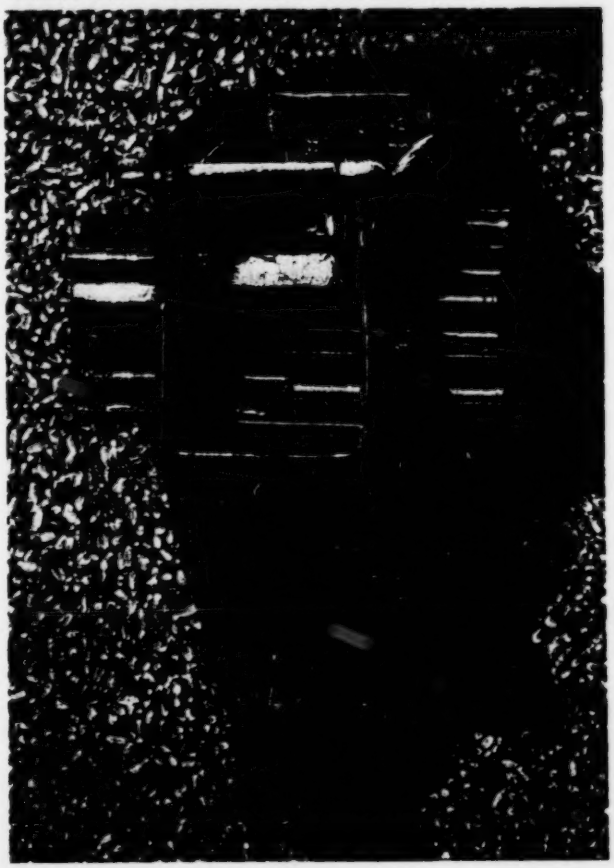
The objective in planting any crop is to place the seed at the optimum depth at a seeding rate which will provide the desired plant density. The seed should be placed in a seedbed which is firm enough so that adequate contact exists between the seed and the surrounding soil to enable germination and rooting to occur.

Since most of the annual grain legumes have a large seed size which is adequately handled by most commercially available grain drills, special seeding equipment is not needed. It is with the small seeded forage legumes that many drills are unable to deliver the proper seeding rate and shallow seeding depth.

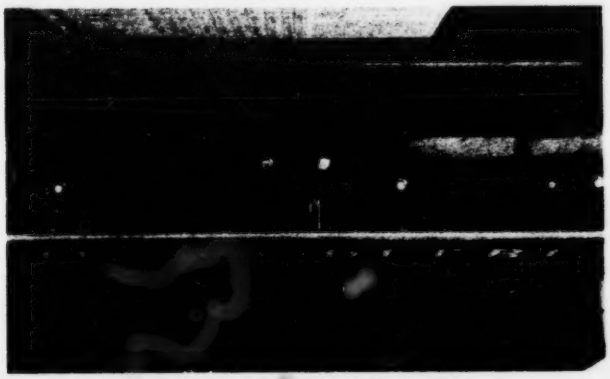
To enable small seeds to be metered out at a sufficiently low rate through a flute-feed system, a smaller diameter flute is needed if the drive shaft speed is to remain constant. The small-seed attachment (commonly called a grass-box) provides this capability and is probably the easiest system to use for anyone who cannot adjust the metering of small seeds by other methods to achieve the desired plant population density.



Double Disk Press Drill with Small-Seed Box



Fluted Roll Feed Cup



Inside of Small Seed Attachment (for wider row spacing individual feed cups can be blocked off with tape and cardboard or plastic).

The double-run metering system, the adjustable feed cup bottom system or the variable speed shaft drive system are other methods of metering small seeds.

Large Seed Compartment is Blocked off

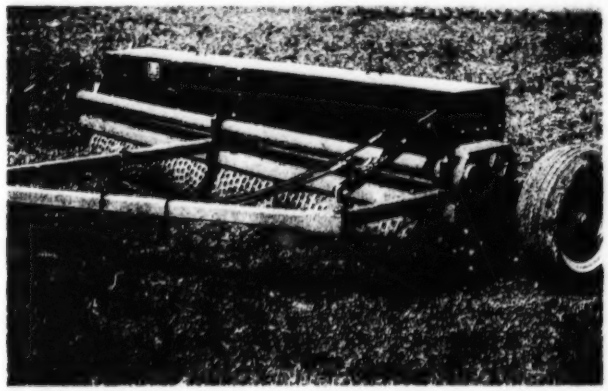
Double-Run Feed Cup Which Provides Separate Metering for Large and Small Seeds.

Air Seeder

Discer

Press Drill

Depth Control Rings and Plates on Double Disk Openers



Brillion Seeder

Other methods of achieving a low seeding rate but possibly with somewhat less precision are the broadcast spreading system and the pneumatic seeding system.

The main point to remember about the placement of small seeded legumes is that if they are seeded over 2 cm (1 in) deep there will likely be insufficient nutrient storage capacity in the seed to enable seedling emergence. In other words, the seedling will run out of energy before it emerges from the soil and can begin to photosynthesize its nutrient requirements. Therefore, small seeded legumes should be placed shallowly at a 1-2 cm (½-¾ in) depth. This can be accomplished by preparing a firm seedbed and by placing depth-control devices on the double disk openers.

The most effective implement for placing seed at a precise depth is the double disk press drill while the discer and air seeder are usually less effective.

Broadcasting the seed and subsequent harrowing is a good alternative if a press drill is not available but care must be taken to ensure that the seed is covered by soil so that it will germinate and grow. The Brillion forage seeder combines surface application of the seed with a packing operation that lifts enough soil to cover the seed and firm the seedbed.

Generally, the most effective implements available in Western Canada for placing the desired seeding rate of small seeds at a precise depth are as follows:

Most Effective: Double Disk Press Drill
Double Disk End Wheel Drill
Hoe Press Drill
Brillion Seeder } are excellent under moist conditions
Broadcast Spreader }
Air Seeder
Less Effective: Discer

In order to accommodate the use of phenoxy herbicides on fields to be seeded to sweetclover with a cereal companion crop, some farmers have found that seeding the cereal crop, applying the herbicide at an early cereal growth stage and then seeding the sweetclover directly into the cereal crop works well. Some damage is done to the cereal crop under this system but in cases where broadleaf weed control is necessary, this method of seeding can be effective for both the sweetclover and cereal crop.

Incorporating Green Manure

Once the legume crop is established and has produced a considerable amount of top and root growth, it may be desirable to incorporate the crop into the soil as green manure. Although the species of legume to be incorporated and the soil type involved may alter one's selection of the appropriate tillage implement, generally the most effective machines are as follows:

Most Effective — Plow (not on erosive soil)
Tandem or Offset Disk
Disk Harrow (Discer)
Less Effective — Deep Tillage Cultivator

In most cases a tandem or offset disk will achieve adequate penetration of the canopy in one pass to incorporate a substantial amount of the topgrowth and at the same time disperse this material throughout the top 10-15 cm (4-6 in) of soil. The plow, on the other hand, does an excellent job of incorporating a large volume of top growth, but lays it all in a dense layer which does not decompose as readily, and in some cases this may result in a "dry layer" which could create subsequent crop growth problems.
Plowing also minimizes trash cover on the soil surface

Moldboard Plow

Tandem Disk

Deep Tillage Cultivator

Keep Soil Conservation In Mind

Remember that the objective of using legumes in your crop rotation is to improve the soil. Although such implements as the plow or heavy duty disk are very effective at incorporating top growth, they can leave light textured or wind-exposed soils extremely susceptible to erosion. Therefore, when choosing tillage implements for working under the legume stand, select one (or a combination) that will incorporate the top growth and roots and still leave a substantial trash cover on the soil surface. Using legume incorporation methods which leave the soil surface bare and vulnerable to erosion can produce results completely opposite to the original objective of soil improvement.

and therefore leaves light textured or wind exposed soils most susceptible to erosion.
The discer will do an adequate job of incorporating legume top growth where adequate penetration can be achieved but more field operations will be required than with the tandem disk.
A cultivator will be least able to incorporate top growth because it does not bring up a large volume of soil to cover the plant material which is to be incorporated.
Experimental results indicate, however, that subsequent crop yield is influenced more by the timing of legume incorporation than by the choice of implement used.

Harvesting Legumes

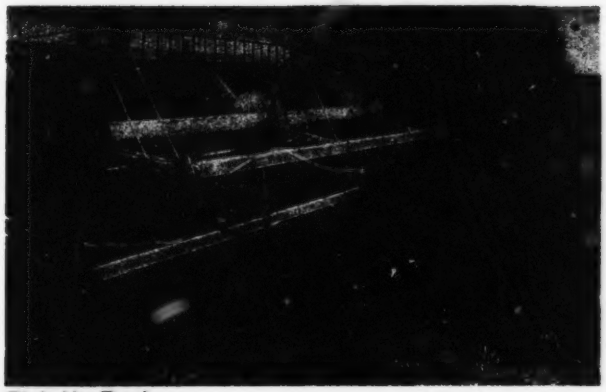
A. Harvesting Hay or Silage

Since most of the equipment used for hay and silage harvesting is fairly common, detail on each type of implement will not be provided here. A comprehensive publication on forage harvesting equipment is "Forage Harvesting Methods" which is available from Saskatchewan Agriculture.

B. Seed Harvesting

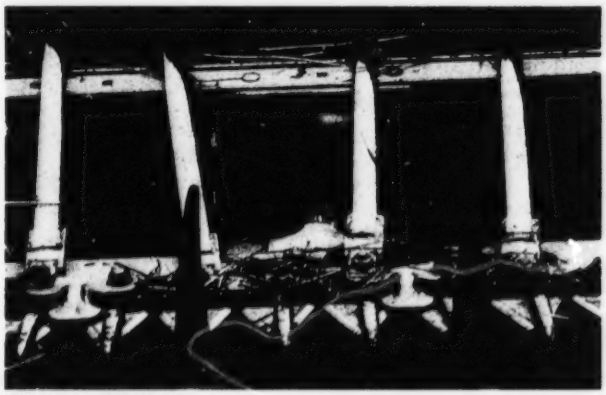
The harvesting of almost all the legumes mentioned in this bulletin can be accomplished by a conventional swather and combine or a combine with a header. The main limitation to harvesting small seeded legume crops is the separating capacity of the combine. Some farmers have found that installing a custom built chaffer enables better separation and retention of small legume seeds.

The primary limitations to harvesting some of the grain legumes is that they lodge severely and therefore crop lifters and/or a pick-up reel are needed on either the swather or the combine header. A floating cutter bar is also helpful.



Pick-Up Reel

The installation of a pick-up reel and floating cutterbar will assist in the harvesting of a severely lodged legume seed crop.



Floating Cutterbar

Conclusions

Legumes have a place in crop rotations to supply nitrogen and organic matter to the soil. Legumes can be used as a cash crop for seed, fodder or high protein dehy. In short term rotations and in drier areas annual (pulse crops) or biennial (sweetclover) legumes provide a considerable amount of nitrogen and organic matter without depleting soil moisture reserves.
In the drier areas legumes for green manure should be used in conjunction with snow trapping and other moisture conservation measures.
In the Black and Grey Wooded soil zones perennial legumes make up an important part of soil conserving rotations. They are used for seed, fodder and dehy. In addition, pulse crops and biennial legumes are used.
Incorporating legumes into farm rotations requires careful management. The seed can be expensive and special techniques are required in seeding to ensure a good stand. Weed control in the seedling crop is often a problem as the use of herbicides may be limited by the legume. Disease and insect control is also more complicated when legumes are underseeded with a nurse crop.
Breaking up a biennial or perennial legume also requires special management. Legumes grown for nitrogen usually provide the most benefit on infertile soil; since at higher fertility levels the luxury use of nitrogen by the legumes themselves can reduce the nitrogen producing efficiency of this system.

Appendix Of References

The following publications are recommended for additional information:

Alfalfa Leafcutter Bees for Pollinating Alfalfa in Western Canada, Agric. Can. Publ. 1495.
Alsike Clover, Agric. Can. Publ. 1264.
Cicer Milkvetch for Western Canada, Agric. Can. Publ. 1536.
Growing and Managing Alfalfa in Canada, Agric. Can. Publ. 1705.
Insect Pests of Legume and Grass Crops in Western Canada, Agric. Can. Publ. 1435.
Red Clover Production, Agric. Can. Publ. 1614.
Sainfoin for Western Canada, Agric. Can. Publ. 1470.
Sweetclover Production in Western Canada, Agric. Can. Publ. 1613.

Alberta Forage Manual, Alta. Agric.
Varieties of Hay and Pasture Crops for Alberta, Alta. Agric., Publ.

Alfalfa Seed Production, Manitoba Agric. Publ.
Alfalfa Seed Production in Manitoba, Man. Alfalfa Seed Producers Assoc. Publ.
Birdsfoot Trefoil Seed Production, Man. Agric. Publ.
Diseases and Deficiencies of Forage, Man. Agric. Publ.
Fababean Production, Manitoba Agric. Publ. 541.
Legume Inoculation, Manitoba Agric. Agdex 120/23.
Nitrogen Fixation and Legumes in Crop Rotation, Man. Agric. Publ. 1982.
Selecting Alfalfa Varieties For Manitoba, Man. Agric. Publ.

Chemical Weed Control in Cereal, Oilseed, Pulse and Forage Crops, Sask. Agric., Publ.
Forage Crop Recommendations, Sask. Agric. Publ.
Insect Control on Field Crops, Sask. Agric. Publ.
Saskatchewan Fertilizer Practices, Sask. Agric. Publ.
Save the Soil, Sask. Agric. Publ.
Soil Salinity, Sask. Agric. Publ.
Understanding Salt Affected Soils, Sask. Agric. Publ.
Varieties of Grain Crops for Saskatchewan, Sask. Agric. Publ.

Dry Pea Production in Saskatchewan, Univ. of Sask. Publ. 225.
Fababean Production in Saskatchewan, Univ. of Sask. Publ. 416.
Guide To Farm Practice in Saskatchewan
Inoculation of Pulse Crops, Univ. of Sask., Publ. 381
Lentil Production in Western Canada, Univ. of Sask. Publ., 413

Pedigreed Forage Seed Production, Canadian Seed Growers Assoc.
Inoculation of Forage Legumes, North Carolina Agricultural Extension Service.

IMPERIAL TO METRIC CONVERSION FACTORS

Imperial units	Approximate conversion factor	Results in:	
LINEAR			
inch	x 25	millimetre	(mm)
foot	x 30	centimetre	(cm)
yard	x 0.9	metre	(m)
mile	x 1.6	kilometre	(km)
AREA			
square inch	x 6.5	square centimetre	(cm^2)
square foot	x 0.09	square metre	(m^2)
acre	x 0.40	hectare	(ha)
VOLUME			
cubic inch	x 16	cubic centimetre	(cm^3)
cubic foot	x 28	cubic decimetre	(dm^3)
cubic yard	x 0.8	cubic metre	(m^3)
fluid ounce	x 28	millilitre	(m/)
pint	x 0.57	litre	(/)
quart	x 1.1	litre	(/)
gallon	x 4.5	litre	(/)
bushel	x 0.36	hectolitre	(h/)
WEIGHT			
ounce	x 28	gram	(g)
pound	x 0.45	kilogram	(kg)
short ton (2000 lb)	x 0.9	tonne	(t)

Imperial units	Approximate conversion factor	Results in:	
TEMPERATURE			
degrees Fahrenheit	(°F -32)x0.56 or (°F -32)x5/9	degrees Celsius	(°C)
PRESSURE			
pounds per square inch	x 6.9	kilopascal	(kPa)
POWER			
horsepower	x 746	watt	(W)
	x 0.75	kilowatt	(kW)
SPEED			
feet per second	x 0.30	metres per second	(m/s)
miles per hour	x 1.6	kilometres per hour	(km/h)
AGRICULTURE			
gallons per acre	x 11.23	litres per hectare	(//ha)
quarts per acre	x 2.8	litres per hectare	(//ha)
pints per acre	x 1.4	litres per hectare	(//ha)
fluid ounces per acre	x 70	millilitres per hectare	(m//ha)
tons per acre	x 2.24	tonnes per hectare	(t/ha)
pounds per acre	x 1.12	kilograms per hectare	(kg/ha)
ounces per acre	x 70	grams per hectare	(g/ha)
plants per acre	x 2.47	plants per hectare	(plants/ha)

Soil Zones of the Prairie Provinces

Legends